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Drucksensor

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## Description

The present invention relates to a pressure sensor including a resistor element. In particular, the present invention relates to a pressure sensor for detecting a relatively small pressure of approximately 0 to 2,000 mmH<sub>2</sub>O or a relatively small load of approximately 0 to 100 g with high accuracy. Furthermore apparatus and a system are provided - claims 11 to 14.

Pressure sensors are widely used for detecting a stress or load applied to components of machines, ships, and vehicles or for detecting an environmental pressure. In this specification, a pressure sensor will also be referred to as a strain sensor or a strain gauge.

A representative strain sensor includes a film formed of a resin such as polyester, epoxy, or polyimide acting as a substrate and a thin-film resistor element formed of a Cu-Ni alloy, a Ni-Cr alloy or the like and provided on the substrate by use of deposition or sputtering. Such a strain sensor is used in the following manner. The substrate thereof is adhered on a surface of the member which receives a stress or load to be measured, using an adhesive resin such as cyanoacrylate. The stress or the load are measured by the strain sensor in the following manner. A degree of strain of the member caused by an external force or load is transmitted to the resistor element through the substrate. Since a cross sectional area of the resistor element and a length of an electrical current path are slightly changed by the strain, the electric resistance of the resistor element is changed. The change in the electric resistance is detected as an electric signal in order to measure the degree of the strain, and the stress and the load applied to the member are detected based on the degree of the strain.

Such a strain sensor is used, for example, as a strain sensor for measuring the load of a suspension for a vehicle. The strain gauge is adhered on a surface of a shaft of the suspension with an adhesive resin or the like in order to detect the load applied on a wheel. Such a usage of the strain gauge as for the suspension, namely, the usage under severe conditions of a temperature range of -50°C to 150°C and a maximum load of 2 tons for a long period of time has a problem in that the adhering strength of the adhesive resin declines and this causes the strain gauge to be peeled off from the component to be measured.

From US-A-4 355 692 a thick film resistor force transducer is known using a metal substrate covered with baked porcelain enamel.

Partially devitrified glass enamel is indicated in JP-A-5-93659 published 16,4,93 (US-A-5 242 722 published 7,9,93).

Such a strain gauge is used for detecting a load applied on a wheel of a vehicle, namely, a load of approximately 0 to 2 tons. It is difficult to detect a relatively small pressure of approximately 0 to 2,000 mmH<sub>2</sub>O or a relatively small load of approximately 0 to 100 g with such a strain gauge with high accuracy.

A pressure sensor according to the present invention includes a plate-shaped metal substrate; a strata; a resistor element which is provided on a surface of the glass layer and has an electric resistance changed in accordance with the degree of strain thereof; and a pair of electrodes connected to the resistor element. The glass layer mainly contains a partially devitrified enamel composition.

Alternatively, the pressure sensor includes a plate-shaped metal substrate; glass layers provided on both surfaces of the metal substrate respectively and mainly containing a partially devitrified enamel composition; a resistor element which is provided on a surface of one of the glass layers and has an electric resistance changed in accordance with the degree of strain thereof; and a pair of electrodes connected to the resistor element.

In a preferred embodiment of the invention, the center of a top surface of the resistor element substantially corresponds to the center of the surface of the metal substrate, and the resistor element and the electrode are each symmetrical with respect to the center thereof.

In a preferred embodiment of the invention, the resistor element and the electrode each have such a shape that provides the resistor element with no directional dependency with respect to pressure or stress.

In a preferred embodiment of the invention, the surface of the resistor element and a top surface of the electrode each have a shape selected from the group consisting of a circular shape, a ring shape, an arc shape, and a polygonal shape.

In a preferred embodiment of the invention, the surface of one of the glass layers is provided with a plurality of the resistor elements and a plurality of the electrodes formed thereon.

In a preferred embodiment of the invention, the surfaces of both of the glass layers are each provided with at least one resistor element and at least a pair of electrodes formed thereon.

In a preferred embodiment of the invention, the partially devitrified enamel composition comprises SiO<sub>2</sub> in the range of 7-33 wt.%, B<sub>2</sub>O<sub>3</sub> in the range of 5 to 31 wt.%, MgO in the range of 20 to 50 wt.%, CaO in the range of 0 to 20 wt.%, BaO in the range of 0 to 50 wt.%, La<sub>2</sub>O<sub>3</sub> in the range of 0 to 40 wt.%, P<sub>2</sub>O<sub>5</sub> in the range of 0 to 5 wt.%, and MO<sub>2</sub> in the range of 0 to 5 wt.%, where M is one element selected from the group consisting of Zr, Ti and Sn.

In a preferred embodiment of the invention, the electrodes each have a thickness of 1/2 or less of the thickness of the resistor element.

In a preferred embodiment of the invention, the electrodes contain gold.

In a preferred embodiment of the invention, the resistor element has a length larger than 1.4 times of a length of a space between the electrodes and is formed by removing a projection at a periphery thereof.

In a preferred embodiment of the invention, the resistor element has an average thickness of 10  $\mu\text{m}$  or less except for a projection at a periphery thereof.

A pressure detecting apparatus according to the present invention includes a pressure sensor according to the present invention which is provided in an engine manifold of a vehicle. An amount of air inhaled into the manifold is controlled by obtaining a difference between a pressure in the manifold and an atmospheric pressure.

Alternatively, an intake pressure detecting apparatus according to the present invention includes a pressure sensor according to the present invention which is provided on a wall of a combustion chamber of a vehicle engine. A pressure in the combustion chamber is directly detected.

A pressure detecting system according to the present invention for use in a vehicle includes a combination of pressure detecting apparatuses according to the present invention.

Alternatively, an intake pressure detecting apparatus according to the present invention includes a pressure sensor according to the present invention which is provided in a main duct of an air conditioning system. A change in an amount of air in the main duct is detected as a pressure.

Thus, the invention described herein makes possible the advantages of providing (1) a pressure sensor for detecting a relatively small pressure of approximately 0 to 2,000  $\text{mmH}_2\text{O}$  or a relatively small load of approximately 0 to 100 g with high accuracy even in severe conditions, (2) a pressure sensor which has no deviation in the resistance or the TCR (temperature dependent change in resistance) when mass-produced and also is usable in an environment where the temperature dynamically changes, and (3) a pressure sensor having a further improved low TCR.

These and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

In the following preferred embodiments of this invention are shown with reference to the accompanying figures, in which

Figure 1A is a plan view of a pressure sensor according to an example of the present invention.

Figure 1B is a cross sectional view of the pressure sensor shown in Figure 1A.

Figure 2 is a view illustrating a method for measuring a change in the resistance of a pressure sensor according to the present invention by applying a load thereto.

Figure 3 is a view illustrating a method for measuring a change in the resistance of a pressure sensor according to a comparative example by applying a load thereto.

Figure 4 is a view illustrating a method according to a comparative example for measuring a change in the resistance of a pressure sensor by applying a load thereto.

Figure 5A is a plan view of a pressure sensor according to another example of the present invention.

Figure 5B is a cross sectional view of the pressure sensor shown in Figure 5A.

Figure 6 is a plan view of a pressure sensor according to yet another example of the present invention.

Figure 7 is a plan view of a pressure sensor according to yet another example of the present invention.

Figure 8 is a plan view of a pressure sensor according to yet another example of the present invention.

Figure 9 is a plan view of a pressure sensor according to a comparative example.

Figure 10 is a plan view of a pressure sensor according to another comparative example.

Figure 11 is a cross sectional view of a pressure sensor according to yet another example of the present invention.

Figure 12 is a plan view of a pressure sensor according to yet another example of the present invention.

Figure 13 is a view illustrating a method for measuring a change in the resistance of a pressure sensor by applying a load thereto.

Figure 14 is a view illustrating a strain of a pressure sensor when a load is applied thereto.

Figure 15 is a cross sectional view of a pressure detecting apparatus for use in a vehicle to which a pressure sensor according to the present invention is applied.

Figure 16 is a view illustrating a plurality of the pressure detecting apparatuses shown in Figure 15 provided in a vehicle.

Figure 17 is a cross sectional view of a static pressure detecting apparatus to which a pressure sensor according to the present invention is applied.

Figure 18 is a view illustrating the static pressure detecting apparatus shown in Figure 17 provided in an air conditioning system.

Figure 19A is a plan view of a pressure sensor according to yet another example of the present invention.

Figure 19B is a cross sectional view of the pressure sensor along line A-A of Figure 19A.

Figure 19C is a cross sectional view of the pressure sensor along line B-B of Figure 19A.

Figure 20A is a plan view of a pressure sensor according to yet another example of the present invention.

Figure 20B is a cross sectional view of the pressure sensor along line A-A of Figure 20A.

Figure 20C is a cross sectional view of the pressure sensor along line B-B of Figure 20A.

Hereinafter, constituting elements of a pressure sensor according to the present invention, a material or composition thereof, and a method for forming the constituting elements will practically be described.

#### (1) Substrate

A substrate for use in a pressure sensor according to the present invention is formed of a metal or an alloy for utilizing the advantages of the present invention. In this specification, the term "metal" also refers to an alloy, and a substrate formed of a metal or an alloy will be referred to as a "metal substrate". The metal substrate may be formed of steel for vitreous enamel, stainless steel, silicon steel, an alloy such as Ni-Cr-Fe, Ni-Fe, covar or invar, or a clad of these substances. It is preferable that the material used for the metal substrate and the glass layer formed thereon have nearly equal expansion coefficients to each other. In the case when the glass layer is formed of a non-alkaline partially devitrified enamel as is described below, the material used for the metal substrate preferably has an expansion coefficient of 100 to  $140 \times 10^{-7}/^{\circ}\text{C}$ , and more preferably is stainless steel.

The metal substrate may be formed into an arbitrary shape in accordance with the pressure to be applied and the usage. If necessary, the metal substrate may be formed into a desirable shape, may have a hole of a desirable shape, or may be subjected to other processing by use of usual mechanical processing, etching, laser processing or the like.

In order to improve the adhesion between the metal substrate and the glass layer, the metal substrate may be surface-stabilized by degreasing a surface thereof and then plating the degreased surface with nickel or cobalt, or by heating the surface to form an oxide film.

#### (2) Glass layer

The glass layer is formed of a material which is excellent in electric insulation and heat resistance, for example, a non-alkaline partially devitrified enamel composition. When the non-alkaline devitrified enamel composition is sintered and cooled, a MgO partially devitrified crystalline phase is deposited, for example. The non-alkaline partially devitrified enamel used for the glass layer may have various compositions. Preferred compositions include MgO in 20 to 50 wt. %,  $\text{SiO}_2$  in 7 to 33 wt. %,  $\text{B}_2\text{O}_3$  in 5 to 31 wt. %, BaO in 0 to 50 wt. %,  $\text{La}_2\text{O}_3$  in 0 to 40 wt. %, CaO in 0 to 20 wt. %,  $\text{P}_2\text{O}_5$  in 0 to 5 wt. %, and  $\text{MO}_2$  in 0 to 5 wt. % (where M is at least one element selected from the group consisting of Zr, Ti, and Sn).

One of the reasons why a partially devitrified enamel is preferred as a material for the glass layer is that this material provides a strong adhesion between the metal substrate and the glass layer. The partially devitrified enamels having the above-mentioned compositions have an especially strong adhesion with the metal substrate.

Another reason for the preference for partially devitrified enamel is that this material provides the glass layer with a resistance against high temperatures. In the case when a resistor element is formed on the glass layer by sintering, a high temperature is required. Accordingly, the glass layer should have a resistance against a temperature of at least  $900^{\circ}\text{C}$ . A partially devitrified enamel composition is resistant against a temperature of approximately up to  $650^{\circ}\text{C}$  because it is not crystallized, but a partially devitrified enamel is resistant against a temperature of at least  $900^{\circ}\text{C}$ . The glass layer formed of the partially devitrified enamel is not fluidized even at a temperature of  $900^{\circ}\text{C}$ . Due to such a property, the glass layer is not strained even when the resistor element is formed by sintering at a temperature of  $850^{\circ}\text{C}$ . In contrast, ordinary non-crystalline glass is not crystallized and thus has a poor temperature resistance. Since such ordinary glass is fluidized at a temperature of as low as  $600^{\circ}\text{C}$ , the resistor element cannot be formed by sintering at a temperature of  $850^{\circ}\text{C}$ , or the components of the glass layer and of the resistor element are mixed with each other so as to change the properties of the resistor element.

The glass layer is formed on the metal substrate by a usual method of spraying, electrostatic powder enameling, electric phorefic enameling, or the like. Electric phorefic enameling is preferable since this method provides an excellent adhesion between the metal substrate and the glass layer, high electric insulation, and the like.

The glass layer is formed on the metal substrate by use of electric phorefic enameling in the following manner.

First, glass, alcohol, and a small amount of water are powdered and mixed for 20 hours in a bowl mill to obtain an average grain size of glass of 1 to  $5 \mu\text{m}$ . The resultant slurry is put into an electrolytic vessel and circulated. Next, the metal substrate is immersed in the slurry as a cathode and polarized at a voltage of 100 to 400 V, thereby allowing glass particles to be deposited on a surface of the metal substrate. Then, the resultant metal substrate is dried and then sintered at a temperature of  $850$  to  $900^{\circ}\text{C}$  for 10 minutes to 1 hour. By this sintering, the glass particles are melted, and simultaneously the components of the glass and of the metal substrate are sufficiently diffused and mixed with each other. As a result, a satisfactory adhesion between the glass layer and the metal substrate can be obtained.

In the case when the above-mentioned sintering is performed while gradually raising the temperature from room temperature to a desired temperature, a great number of fine needle crystals are deposited. Such crystals provide an anchor effect, and simultaneously the adhesion between the glass layer and the metal substrate is improved, which is

more preferable.

### (3) Resistor element

For a resistor element, various materials may be used, the electric resistance of which is changed in accordance with the degree of strain. For example, a metal such as nickel, chrome, copper, iron, or ruthenium, an alloy such as a Cu-Ni alloy or a Ni-Cr alloy, or a metal oxide such as ruthenium oxide may be used.

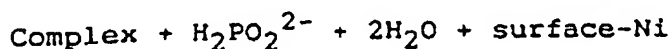
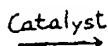
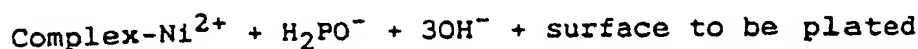
The resistor element is formed by printing, plating (non-electric plating, transfer printing or the like as is described below.

According to one of the printing methods, the resistor element is formed on the glass layer in the following manner. First, a paste containing an organic metal compound mainly containing one of Bi, Rh, V and Sb is formed. The paste is printed on a surface of the glass layer, and then is subjected to thermal decomposition. Thus, a metal film or an alloy film is obtained so as to act as a resistor element. The paste used for this method preferably contains a metal selected from the group consisting of nickel, chrome, copper, iron, and ruthenium, and further at least two types of thermally decomposable organic compounds containing one of Bi, Rh, V, and Sb as additives.

According to another printing method, the resistor element is formed on the glass layer in the following manner. First, a paste containing ruthenium oxide and glass frit such as borosilicate glass as main components is formed. The paste is printed on the glass layer and then sintered. The paste preferably contains a filler ( $ZrO_2$  or the like), bismuth oxide, ethyl cellulose, acetate ester of butylcarbitol (or terpineol) and the like in addition to the above-mentioned main components.

For forming a resistor element by non-electric plating, an assembly of the metal substrate and the glass layer is immersed in a plating liquid. The plating liquid includes a metal complex and a reducing agent such as hypophosphorous acid. The metal complex may contain a metal complex such as Cu-Ni-P, Ni-Cr-P, or Ni-Fe-P. These materials are satisfactory in sensitivity to strain and resistance against high temperatures and thus are suitable for use as a pressure sensor for detecting a relatively small pressure or a pressure sensor used under the environment where temperature is dynamically changed.

Electrons released by oxidation of the reducing agent reduces metal ions in the metal complex to allow the metal deposited on a surface which is to be plated. A general reaction occurring in the case when Ni is deposited is expressed by Scheme I.



Scheme I

When the surface to be plated is a metal, metal ions in the plating liquid and the ions of the surface to be plated are first substituted at an initial stage of immersion, and then reduction occurs. Since the atoms of the plating metal deposited on the surface act as an auto-catalyst thereafter, reduction of the plating metal smoothly progresses.

When the surface to be plated is an insulating material, the ion substitution does not occur at an initial stage of immersion. In this case, by absorbing Sn ions of tin chloride and Pd ions of palladium chloride to the insulating material in advance, the ion substitution occurs at an initial stage of immersion and then the reduction occurs. Thereafter, the metal deposited on the surface acts as an auto-catalyst as in the case when the surface to be plated is a metal, thereby progressing the reduction.

The non-electric plating is preferable for producing a pressure sensor including a glass layer formed of a partially devitrified enamel for the following reason. The glass layer formed of a partially devitrified enamel has fine needle crystals on a surface thereof, and thus is porous. When such a glass layer is plated, reduction starts in an inner portion of the glass layer. The resulting plating layer provides an anchor effect, thereby improving the adhesion between the plating layer and the glass layer. In contrast, a usual non-crystalline glass layer or a plastic layer has a smooth surface. Since no anchor effect is provided by the smooth surface, the adhesion thereof with the plating layer is poor.

It is preferable to provide a catalyst layer including tin, palladium or the like on a surface of the glass layer in

advance and then form the resistor element on a surface of the catalyst layer. Thus, a better anchor effect is obtained, thereby the adhesion between the glass layer and the resistor element is greatly improved.

After a resistor element is formed by any of the above-mentioned methods, it is preferable to process the resistor element to a fine pattern. A resistor element formed by non-electric plating can be processed either by:

Method (1) The resistor element is cut into a specified pattern by laser, or

Method (2) By photolithography, unnecessary portions of the resistor element is removed. It is also possible to form a resistor element by non-electric plating in combination with a lift-off process which uses a plating condition-resistive resist having an excellent resistance against a plating liquid which is a strong acid or a strong alkali and used under a high temperature of 80 to 95°C. The plating condition-resistive resist is preferably formed of a UV-curable acrylic resin having a satisfactory print-ability and a short curing time.

For forming a resistor element by transfer printing, a foil of a Cu-Ni alloy or a Ni-Cr alloy is preferably used. According to this method, one of the surfaces of the foil is coated with a resin, and then a resist is painted on the other surface of the foil. Then, etching is performed so as to obtain a resistor element in a specified pattern. The resultant resistor element is fixed on the glass layer on the metal substrate with the resin, and then sintered.

The pattern is transferred on the glass layer with high accuracy by using the resin for fixing the resistor element. The resin is solved in an appropriate solvent and adjusted so as to have a desirable viscosity prior to being sprayed or printed on the foil. Alternatively, a layer of the resin is laminated on the foil. The resin is removed by sintering. Preferable resins include acrylic resins such as polyacrylate and polymethacrylate, vinyl chloride, a copolymer of vinyl chloride and polyacrylate, and the like. Such resins are excellent in combustibility and do not have any adverse affect on the glass layer or the alloy foil. Further, since a degree of shrinkage due to the heat is small, these resins assist the transfer of the pattern of the foil with high accuracy.

The printing, the plating, and the transfer printing methods are easy and low-cost methods for forming a resistor element on a glass layer which are also suitable for mass production.

#### (4) Electrode

An electrode is prepared by printing a paste formed of various metals and a glass paste on a surface of the glass layer and sintering the glass layer with the paste. As the glass paste, a Ag-Pd or an Ag glass paste can be used. As the paste formed of metals, a paste including an organic metal compound mainly containing Au as a conducting component and at least two types of thermally decomposable organic compounds containing one of Si, Bi, Rh, V, and Sb as additives is preferable. In addition to Au, an organic metal compound containing Pd can arbitrarily be added as a conducting component.

Electrodes connected to the resistor element may be formed in various conventional methods before, after, or simultaneously with the formation of the resistor element.

If necessary, an overcoating layer of glass or a resin may be formed on the resistor element.

A pressure sensor is used in various ways in accordance with an object for measurement. Some examples will be described, hereinafter.

(1) For detecting a load or a stress of approximately 0 to 2 tons applied to a wheel of an automobile, a pressure sensor is adhered on a shaft or other parts which receives the load and is strained. In this way, the strain transmitted to the pressure sensor can indirectly be detected. In this case, since the pressure sensor only indirectly receives the stress, the pressure sensor can withstand even a relatively large stress. Although the glass layer used in the pressure sensor is fragile against a tensile stress, the part of the object on which the pressure sensor is adhered shrinks in this case. Accordingly, the pressure sensor receives a compressive stress, and thus can withstand even a relatively large stress.

(2) For detecting an environmental pressure, a pressure sensor is attached to a material in an environment to be measured. Since the pressure is uniformly applied to the pressure sensor from all directions, the sensor is relatively highly resistant against breakage.

(3) For directly detecting a load, a pressure sensor is arranged so as to directly receive the load as is shown in Figure 2 or 3. In this case, since the whole load is directly applied to the resistor element of the pressure sensor, even a small load of several hundred grams is sufficient to break the pressure sensor.

Since a pressure sensor according to the present invention is used in different ways in different examples, a pressure sensor which is not appropriate to an example is considered to be satisfactory in another example. In the usage

of (2), since a stress or a pressure is directly applied to the resistor element, the center of the metal substrate or a glass layer is not required to correspond to the center of the resistor element. However, in the usages of (1) and (3), the center of the metal substrate or the glass layer is required to correspond to the center of the resistor element.

Hereinafter, the present invention will be described by way of illustrating examples with reference to the accompanying drawings.

#### Example 1

On a surface of a metal substrate formed of SUS430 (100 mm x 100 mm x 0.5 mm), a glass layer formed of a partially devitrified enamel having each of the compositions shown in Tables 1 through 5 was formed in a thickness of 100  $\mu\text{m}$ , and was sintered at a temperature of 880°C for 10 minutes. Samples thus obtained were evaluated for surface properties of the glass layer such as surface roughness and surface winding, heat resistance of the glass layer, adhesion between the metal substrate and the glass layer (also referred to simply as "adhesion"). The results are also shown in Tables 1 through 5.

The surface roughness was measured by a Talysurf surface roughness meter and shown by Ra, an average roughness at a central line of the surface. A smaller value of Ra is more preferable. The surface winding is shown by Rmax, the maximum difference between a peak with a maximum height and a trough with a minimum height measured by the Talysurf surface roughness meter. A smaller value of Rmax is more preferable.

In order to find out the heat resistance, a spalling test was repeated in which the samples were kept in an electric oven at a temperature of 850°C for 10 minutes and then naturally cooled outside the oven for 30 minutes. Abnormalities such as cracks and peelings-off generated in the samples were examined. The cracks were visually checked after the samples were immersed in a red ink, taken out of the ink, and then the ink on the surface was wiped off. In Tables 1 through 5, O indicates no abnormality was generated after 10 cycles of the spalling test;  $\Delta$  indicates an abnormality was generated after 5 to 9 cycles; and X indicates an abnormality was generated after 4 cycles or less.

The adhesion was examined by bending the samples. In Tables 1 through 5, X indicates the glass layer was peeled off so as to expose the surface of the metal substrate;  $\Delta$  indicates the surface of the metal substrate was partially exposed; and O indicates the surface of the metal substrate was not exposed.

Table 1

Sample No.	1	2	3	4	5	6	7	8	9
Composition (wt.%)									
MgO	39	39	39	39	39	39	39	39	10
BaO	12	12	12	12	12	12	12	12	10
CaO	3	3	3	3	3	3	3	3	3
La <sub>2</sub> O <sub>3</sub>	5	5	5	5	5	5	5	5	5
B <sub>2</sub> O <sub>3</sub>	0	5	10	15	25	30	31	33	46
SiO <sub>2</sub>	38	33	28	23	13	8	7	5	23
ZrO <sub>2</sub>	2	2	2	2	2	2	2	2	2
TiO <sub>2</sub>									
SnO <sub>2</sub>									
P <sub>2</sub> O <sub>5</sub>	1	1	1	1	1	1	1	1	1
ZnO									
SiO <sub>2</sub> /B <sub>2</sub> O <sub>3</sub> ratio	$\infty$	6.6	2.8	1.53	0.52	0.27	0.22	0.15	0.50
Surface roughness( $\mu\text{m}$ )	0.6	0.5	0.46	0.38	0.05	0.06	0.06	0.08	0.09
Winding( $\mu\text{m}$ )	5.2	3.3	3.2	2.5	0.5	1.0	1.0	0.9	1.2
Heat resistance	O	O	O	O	O	O	O	X	X
Adhesion	O	O	O	O	O	O	O	O	O
Overall evaluation	X	O	O	O	O	O	O	X	X

Table 2

Sample No.	10	11	12	13	14	15	16	17	18
Composition (wt.%)									
MgO	10	20	29	40	50	55	40	40	40
BaO	10	10	10	10	10	10	5	5	5
CaO	3	3	3	3	3	3		10	20
La <sub>2</sub> O <sub>3</sub>	5	5	5	5	5	5	5	5	5
B <sub>2</sub> O <sub>3</sub>	42	39	33	26	19	16	31	25	18
SiO <sub>2</sub>	21	20	17	13	10	8	16	12	9
ZrO <sub>2</sub>	2	2	2	2	2	2	2	2	2
TiO <sub>2</sub>									
SnO <sub>2</sub>									
P <sub>2</sub> O <sub>5</sub>	1	1	1	1	1	1	1	1	1
ZnO									
SiO <sub>2</sub> /B <sub>2</sub> O <sub>3</sub> ratio	0.50	0.51	0.52	0.5	0.53	0.5	0.52	0.48	0.5
Surface roughness(μm)	0.08	0.07	0.05	0.07	0.10	0.18	0.08	0.05	0.09
Winding(μm)	1.1	0.5	0.9	0.5	0.8	1.5	0.2	0.6	0.9
Heat resistance	○	○	○	○	○	○	○	○	○
Adhesion	○	○	○	○	○	Δ	○	○	○
Overall evaluation	○	○	○	○	○	×	○	○	○

Table 3

Sample No.	19	20	21	22	23	24	25	26	27
Composition (wt.%)									
MgO	40	20	20	20	20	20	30	30	30
BaO	5		20	40	50	60	5	5	5
CaO	25	2	2	2	2	2	2	2	2
La <sub>2</sub> O <sub>3</sub>	5	5	5	5	5	5		10	30
B <sub>2</sub> O <sub>3</sub>	15	47	33	20	13	7	40	33	20
SiO <sub>2</sub>	7	23	17	10	7	3	20	17	10
ZrO <sub>2</sub>	2	2	2	2	2	2	2	2	2
TiO <sub>2</sub>									
SnO <sub>2</sub>									
P <sub>2</sub> O <sub>5</sub>	1	1	1	1	1	1	1	1	1
ZnO									
SiO <sub>2</sub> /B <sub>2</sub> O <sub>3</sub> ratio	0.47	0.49	0.52	0.5	0.54	0.43	0.5	0.52	0.5
Surface roughness(μm)	0.14	0.09	0.08	0.06	0.05	0.05	0.10	0.08	0.08
Winding(μm)	1.5	0.9	0.6	0.6	0.5	0.5	1.1	0.9	0.9
Heat resistance	○	○	○	○	Δ	×	○	○	○
Adhesion	Δ	○	○	○	Δ	Δ	○	○	○
Overall evaluation	×	○	○	○	Δ	×	○	○	○

Table 4

Sample No.	28	29	30	31	32	33	34	35	36
Composition (wt.%)									
MgO	30	30	40	40	40	40	40	40	40
BaO	5	5	10	10	10	10	10	10	10



Table 4 (continued)

Sample No.	28	29	30	31	32	33	34	35	36
Composition (wt.%)									
CaO	2	2	3	3	3	3	3	3	3
La <sub>2</sub> O <sub>3</sub>	40	45	5	5	5	5	5	5	5
B <sub>2</sub> O <sub>3</sub>	13	7	27	24	23	27	24	23	27
SiO <sub>2</sub>	7	3	14	12	11	14	12	11	14
ZrO <sub>2</sub>	2	2		5	7				
TiO <sub>2</sub>							5	7	
SnO <sub>2</sub>									
P <sub>2</sub> O <sub>5</sub>	1	1	1	1	1	1	1	1	1
ZnO									
SiO <sub>2</sub> /B <sub>2</sub> O <sub>3</sub> ratio	0.54	0.43	0.52	0.5	0.49	0.52	0.5	0.49	0.52
Surface roughness(μm)	0.07	0.06	0.05	0.08	0.12	0.05	0.08	0.13	0.05
Winding(μm)	0.9	0.8	0.5	0.9	1.5	0.5	1.0	1.6	0.6
Heat resistance	Δ	×	○	○	○	○	○	○	○
Adhesion	○	○	○	○	○	○	○	○	○
Overall evaluation	Δ	×	○	○	×	○	○	×	○

Table 5

Sample No.	37	38	39	40	41	42
Composition (wt.%)						
MgO	40	40	40	40	40	40
BaO	10	10	10	10	10	10
CaO	3	3	3	3	3	3
La <sub>2</sub> O <sub>3</sub>	5	5	5	5	5	5
B <sub>2</sub> O <sub>3</sub>	24	23	28	24	23	27
SiO <sub>2</sub>	12	11	14	12	11	14
ZrO <sub>2</sub>						
TiO <sub>2</sub>						
SnO <sub>2</sub>	5	7				
P <sub>2</sub> O <sub>5</sub>	1	1	1	1	1	1
ZnO				5	7	
SiO <sub>2</sub> /B <sub>2</sub> O <sub>3</sub> ratio	0.5	0.49	0.5	0.5	0.49	0.52
Surface roughness(μm)	0.09	0.12	0.06	0.08	0.13	0.05
Winding(μm)	0.9	1.6	0.7	1.0	1.6	0.6
Heat resistance	○	○	○	○	○	○
Adhesion	○	○	○	○	○	○
Overall evaluation	○	×	○	○	×	○

Samples 1 through 8 have different amounts of SiO<sub>2</sub> and B<sub>2</sub>O<sub>3</sub> with the amounts of the other components being identical with one another.

Samples 9 through 15 have different amounts of MgO with the SiO<sub>2</sub>/B<sub>2</sub>O<sub>3</sub> ratio substantially identical with one another.

Samples 16 through 19 have different amounts of CaO with the SiO<sub>2</sub>/B<sub>2</sub>O<sub>3</sub> ratio substantially identical with one another.

Samples 20 through 24 have different amounts of BaO with the SiO<sub>2</sub>/B<sub>2</sub>O<sub>3</sub> ratio substantially identical with one another.

Samples 25 through 29 have different amounts of La<sub>2</sub>O<sub>3</sub> with the SiO<sub>2</sub>/B<sub>2</sub>O<sub>3</sub> ratio substantially identical with one another.

Samples 30 through 42 have different amounts of ZrO<sub>2</sub>, TiO<sub>2</sub>, SnO<sub>2</sub> or ZnO with the SiO<sub>2</sub>/B<sub>2</sub>O<sub>3</sub> ratio substantially

identical with one another.

$\text{SiO}_2$  and  $\text{B}_2\text{O}_3$  are oxides which form the basic framework of glass.  $\text{MgO}$ ,  $\text{BaO}$  and  $\text{CaO}$ , which are referred to as network modifier oxide, significantly influence the melting point and the crystallinity of glass.  $\text{La}_2\text{O}_3$  improves the adhesion between the metal substrate and the glass layer.  $\text{ZrO}_2$ ,  $\text{TiO}_2$ ,  $\text{SnO}_2$ , or  $\text{P}_2\text{O}_5$  forms a core of a crystal.

As is apparent from Tables 1 through 5, a sample having a high  $\text{SiO}_2$  content is strong in heat resistance but poor in surface properties and adhesion. Needless to say, a sample having a low  $\text{SiO}_2/\text{B}_2\text{O}_3$  ratio is poor in heat resistance but good in surface properties and adhesion. According to the present invention, the material for the glass layer preferably contains  $\text{SiO}_2$  in the range of 7 to 33 wt.% and  $\text{B}_2\text{O}_3$  in the range of 5 to 31 wt.%, with a preferable  $\text{SiO}_2/\text{B}_2\text{O}_3$  ratio of 0.22 to 6.6.

The amount of  $\text{MgO}$  is relevant to a degree of devitrification. When  $\text{MgO}$  is contained in less than 20 wt.%, crystal deposition is insufficient, thereby deteriorating the heat resistance of the glass layer. When  $\text{MgO}$  is contained in more than 50 wt.%, crystals are easily deposited when the glass is melted. In such a case, the glass hardly obtains a uniform quality, and further have a high surface roughness and a poor adhesion. Accordingly,  $\text{MgO}$  is preferably contained in the range of 20 to 50 wt. %.

When  $\text{CaO}$  is contained in more than 20 wt.%, the glass layer has poor surface properties, but when  $\text{CaO}$  is contained in 20 wt.% or less, there is no adverse affect. Accordingly,  $\text{CaO}$  is preferably contained in 0 to 20 wt.%.

When  $\text{BaO}$  is contained in more than 50 wt.%, the heat resistance of the glass layer and the adhesion are deteriorated, but when  $\text{BaO}$  is contained in 50 wt.% or less, there is no adverse affect. Accordingly,  $\text{BaO}$  is preferably contained in 0 to 50 wt.%.

When  $\text{La}_2\text{O}_3$  is contained in more than 40 wt.%, the heat resistance of the glass layer deteriorates, but when  $\text{La}_2\text{O}_3$  is contained in 40 wt.% or less, there is no adverse affect. Accordingly,  $\text{La}_2\text{O}_3$  is preferably contained in 0 to 40 wt.%.

Although all the samples contains  $\text{P}_2\text{O}_5$  in an identical amount in Example 1, it has been confirmed that desirable properties are obtained when  $\text{P}_2\text{O}_5$  is obtained in 0 to 5 wt.%. When  $\text{P}_2\text{O}_5$  is contained in more than 5 wt.%, the surface properties deteriorate.

Other components which may be added, namely,  $\text{ZrO}_2$ ,  $\text{TiO}_2$ ,  $\text{SnO}_2$ , and  $\text{ZnO}$  are each preferably contained in 0 to 5 wt.%. When these components are each contained in more than 5 wt.%, the surface properties deteriorate.

#### Example 2

A pressure sensor according to the present invention produced by any of the general methods described in the introductory part of the description of the preferred embodiments will be described with reference to Figures 1A and 1B.

A plate-shaped metal substrate 1 having an outer diameter of 40 mm and a thickness of 60  $\mu\text{m}$  was pre-treated by degreasing, rinsing, acid washing, rinsing, nickel plating, and then rinsing. The resultant metal substrate 1 was immersed in a slurry containing the partially devitrified enamel particles having the composition of Sample 7 in Table 1, and a voltage was directly applied between a counter electrode and the metal substrate 1 so as to coat the metal substrate 1 with the glass particles, by use of the above-mentioned electric phoretic enameling. The temperature was raised from room temperature to 880°C in 4 hours, and the resultant metal substrate 1 coated with the glass particles was sintered at this temperature for 10 minutes, thereby forming a glass layer 2 of the partially devitrified enamel. A Ag-Pd paste was printed in a specified pattern on a surface of the glass layer 2, and then sintered at a temperature of 850°C, thereby forming a pair of electrodes 3. A paste mainly including ruthenium oxide and glass frit was printed in a specified pattern between the electrodes 3, and then sintered at a temperature of 830°C, thereby forming a resistor element 4. Thus, a pressure sensor according to the present invention was produced. Figure 1A is a plan view of the resultant pressure sensor, and Figure 1B is a cross sectional view thereof.

#### Example 3

Another pressure sensor was produced in the same manner as in Example 2 except that a metal foil having a thickness of 200  $\mu\text{m}$  was used instead of the plate-shaped metal substrate 1.

#### Comparative Example 1

A glass layer was formed on both surfaces of a metal foil having a thickness of 60  $\mu\text{m}$  instead of on the plate-shaped metal substrate 1, and then a resistor element which is identical with the one in Example 2 was formed on one of the surfaces of the glass layer, thereby producing a pressure sensor as a comparative example.

#### Example 4

As is shown in Figure 2, the pressure sensors produced in Examples 2 and 3 were each fixed on a fixing table 5

so that a load would be applied perpendicularly to a surface of the resistor element 4. The electrodes 3 each had a lead wire 6 connected thereto so that the resistance of the resistor element 4 could be measured.

As is shown in Figure 3, the pressure sensor produced in Comparative Example 1 was fixed on the fixing table 5 so that a load would be applied perpendicularly to a surface of the resistor element 4.

#### Comparative Example 2

As Comparative Example 2, the pressure sensor produced in Example 2 was fixed on the fixing table 5 so that a load would be applied perpendicularly to a surface of the pressure sensor opposite to the surface on which the resistor element 4 is formed.

The sensors according to Examples 2 and 3 and Comparative Examples 1 and 2 were applied with weights of 500 mg, 1 g, 5 g, 10 g, and 50 g, and evaluated for a change ratio in the resistance. The results are shown in Table 6.

Table 6

Load versus change ratio in the resistance (%)					
	500 mg	1 g	5 g	10 g	50 g
Example 2	0.010	0.018	0.088	0.174	0.877
Example 3	0.002	0.004	0.021	0.040	0.213
Comparative Example 1	0.007	0.014	0.069	0.136	crack
Comparative Example 2	-	-	0.005	0.011	0.053

When a load in the range of 500 mg to 50 g was applied to the pressure sensors according to Examples 2 and 3, the change ratio in the resistance of each pressure sensor was linearly changed. This fact means that a relatively small load or pressure can be measured. No crack or peeling-off was generated in the glass layers 2 of the pressure sensors according to Examples 2 and 3.

In the pressure sensor according to Comparative Example 1, cracks were generated in the lower glass layer 2 by a load of 50 g since a tensile stress was applied to the lower glass layer 2 by the load.

The pressure sensor according to Comparative Example 2 did not detect a load of 5 g or less, and cracks were generated in the glass layer 2 by a load of 100 g or more, since a tensile stress was applied to the glass layer 2 by the load. In contrast, in the case when the pressure sensor which is identical with the one according to the Comparative Example 2 is provided in such a manner that a load is applied to the glass layer 2 on the metal substrate 1 as is shown in Figure 2, the glass layer 2 receives only a compressive stress but not a tensile stress.

Since the pressure sensors according to Examples 2 and 3 each have a high sensitivity, as is apparent from the above experiment, these pressure sensors can be used as sensors for detecting the vapor pressure of a liquid. In the experiment described in Example 4, for example, a load of 1.7 g corresponds to a vapor pressure of 1 mmHg.

#### Example 5

Yet another pressure sensor was produced in the same manner as in Example 2 except that the glass layers 2 were formed on both surfaces of the metal substrate 1. It should be noted that the resistor element 4 was formed within 1.5 mm from the center of the metal substrate 1 so that the center of the resistor element 4 corresponds to the center of the metal substrate 1. Figure 5A is a plan view of the pressure sensor according to Example 5, and Figure 5B is a cross sectional view thereof.

#### Example 6

Yet another pressure sensor was produced in the same manner as in Example 5 except that a resistor element 4 and electrodes 3 both having a shape of a regular octagon were formed within 1.5 mm from the center of the metal substrate 1 as is shown in Figure 6. The center of the resistor element 4 corresponds to the center of the metal substrate 1.

#### Example 7

Yet another pressure sensor was produced in the same manner as in Example 5 except that a resistor element 4 and electrodes 3 both having a circular shape were formed within 1.5 mm from the center of the metal substrate 1 as is shown in Figure 7. The center of the resistor element 4 corresponds to the center of the metal substrate 1.

Example 8

Yet another pressure sensor was produced in the same manner as in Example 5 except that a circular resistor element 4 and arc-shaped electrodes 3 were formed at the center of the metal substrate 1 as is shown in Figure 8.

The center of the resistor element 4 corresponds to the center of the metal substrate 1.

Comparative Example 3

A pressure sensor was produced in the same manner as in Example 5 except that a resistor element 4 and electrodes 3 both having the same shape as in Example 5 were formed at 10 mm away from the center of the metal substrate 1 as is shown in Figure 9. The center of the resistor element 4 does not correspond to the center of the metal substrate 1.

Comparative Example 4

A pressure sensor was produced in the same manner as in Example 5 except that a resistor element 4 and electrodes 3 were formed at 10 mm away from the center of the metal substrate 1 as is shown in Figure 10. The center of the resistor element 4 corresponds to the center of the metal substrate 1.

Comparative Example 5

The metal substrate 1 was coated with a partially devitrified enamel in the same manner as in Example 5, and then a commercially available strain gauge was adhered on the metal substrate 1. The center of the strain gauge corresponds to the center of the metal substrate 1.

Example 9

In the pressure sensor according to Example 5, the resistor element 4 has a top surface which is symmetrical with respect to the center thereof, and the center of the metal substrate 1 and the center of the resistor element 4 substantially correspond to each other.

In the pressure sensor according to Example 6, the resistor element 4 and the electrodes 3 each have a profile of a regular octagon which is symmetrical with respect to the center thereof. Further, since the center of the metal substrate 1 and the center of the resistor element 4 substantially correspond to each other, the pressure sensor has no directional dependency. In other words, the sensitivity of the pressure sensor is not changed in accordance with the direction in which a force is applied.

In the pressure sensor according to Example 7, the resistor element 4 and the electrodes 3 each have a circular shape which is symmetrical with respect to the center thereof. Further, since the center of the metal substrate 1 and the center of the resistor element 4 substantially correspond to each other, the pressure sensor has no directional dependency.

In the pressure sensor according to Example 8, the resistor element 4 is circular and the electrodes 3 are arc-shaped. Further, since the center of the metal substrate 1 and the center of the resistor element 4 substantially correspond to each other, the pressure sensor has no directional dependency.

In the pressure sensor according to Comparative Example 3, although the resistor element 4 is symmetrical with respect to the center thereof, the center of the metal substrate 1 and the center of the resistor element 4 do not correspond to each other.

In the pressure sensor according to Comparative Example 4, although the center of the metal substrate 1 and the center of the resistor element 4 correspond to each other, neither the resistor element 4 nor the electrodes 3 are symmetrical with respect to the center thereof. Accordingly, the pressure sensor has directional dependency.

The pressure sensors according to Examples 5 through 8 and Comparative Examples 3 through 5 were mounted on a jig 5 as is shown in Figure 13. Pressures of 0, 400, 800, 1,200, 1,600, and 2,000 mmH<sub>2</sub>O were applied on a surface of each pressure sensor opposite to the surface on which the resistor element was formed. The results are shown in Table 7.

Table 7

Pressure versus change ratio in the resistance (%)						
Pressure (mmHg)	0	400	800	1200	1600	2000
Example 5	0	0.119	0.241	0.360	0.477	0.587
Example 6	0	0.126	0.250	0.376	0.501	0.626
Example 7	0	0.148	0.294	0.441	0.590	0.737
Example 8	0	0.139	0.279	0.418	0.556	0.696
Comparative Example 3	0	0.059	0.118	0.180	0.239	0.301
Comparative Example 4	0	0.072	0.142	0.214	0.288	0.355
Comparative Example 5	0	0.014	0.029	0.042	0.056	0.071

In the pressure sensors according to Examples 5 through 8, the top surface of the resistor element 4 is symmetrical with respect to the center thereof. Since the center of the metal substrate 1 corresponds to the center of the resistor element 4, a strain caused by a compressive stress or a tensile stress generated when a pressure is applied to the pressure sensor is uniformly distributed from the center of the resistor element 4 to all the directions. Further, the center of the resistor element 4 has a maximum degree of strain, and thus has the highest change ratio in the resistance of the resistor element 4. In the pressure sensors according to Comparative Examples 3 through 5, the strain is not uniformly distributed from the center of the resistor element 4 in all directions, and the center of the resistor element 4 does not have a maximum degree of strain. Accordingly, the sensitivity is low.

The pressure sensors according to Examples 6 through 8 are superior to the pressure sensor according to Example 5 in the following points.

In the case when the pressure sensor according to Example 5 is adhered on such a member that receives a stress only in one particular direction, for example, a suspension of a vehicle, the sensitivity is changed in accordance with the direction in which the pressure sensor is adhered. Namely, the pressure sensor has the directional dependency. In the case of the pressure sensors according to Examples 6 through 8, in contrast, the sensitivity is not changed. Namely, the pressure sensors have no directional dependency.

The difference between the pressure sensors according to Examples 5 and those according to Examples 6 through 8 will be described in more detail.

Supposing that forces (i.e., pressure, stress or load) are applied in different directions **a**, **b** and **c** to the pressure sensor according to Example 5 as is shown in Figure 5A, the force in the direction of **a** enlarges a cross sectional area of the resistor element 4 and also reduces the length thereof. Accordingly, the resistance of the resistor element 4 is decreased. The forces from the directions **b** and **c** reduce the cross sectional area of the resistor element 4 and thus increase the resistance thereof. In other words, the forces in the directions **b** and **c** lower the sensitivity of the resistor element 4.

In the case of the pressure sensors according to Examples 6 through 8, the force in any direction **a**, **b** or **c** enlarges the cross sectional area of the resistor element 4 and reduces the length thereof, thereby improving the sensitivity thereof.

As is apparent from Table 7, the pressure sensors according to Examples 5 through 8 of the present invention have a higher sensitivity to a pressure than the pressure sensors according to Comparative Examples 3 through 5. Especially, the pressure sensors according to Examples 6 through 8 with no directional dependency have excellent sensitivity.

#### Example 10

As is shown in Figure 11, both surfaces of the metal substrate 1 were coated with glass layers 2, and resistor elements **R1** and **R2** and electrodes 3 each having an identical shape and an identical resistance with those in Example 7 were formed on the glass layers 2 respectively in the same manner as in Example 5, thereby producing still another pressure sensor. Centers of the resistor elements **R1** and **R2** correspond to the center of the metal substrate 1.

#### Example 11

As is shown in Figure 12, circular resistor elements **R3** (inner) and **R4** (outer) and circular electrodes 3 were formed on the glass layer 2 in the same manner as in Example 5, thereby producing still another pressure sensor. The inner resistor elements **R3** was formed so as to have the center thereof within 15 mm from the center of the metal substrate 1, and the outer resistor element **R4** was formed within 15 mm from the center of the metal substrate 1. Further, the

resistor element **R3** and **R4** were formed so that the centers thereof correspond to the center of the metal substrate **1**.

#### Example 12

The pressure sensors according to Examples 10 and 11 were evaluated for a change ratio in the resistance of the resistor elements **R1**, **R2**, **R3**, and **R4**. The resistor elements **R1**, **R3** and **R4** were applied with a tensile stress. The results are shown in Table 8.

Table 8

Pressure versus change ratio in the resistance (%)							
Pressure (mmHg)		0	400	800	1200	1600	2000
Example 10	R1	0	0.148	0.294	0.441	0.590	0.737
	R2	0	-0.148	-0.292	-0.440	-0.588	-0.735
Example 11	R3	0	0.149	0.294	0.442	0.590	0.737
	R4	0	-0.032	-0.063	-0.096	-0.126	-0.158

The resistor elements **R1** and **R2** of the pressure sensor according to Example 10 are considered to be one resistor element. In other words, the absolute values of the change ratio in the resistance of the resistor elements **R1** and **R2** are added. The sum thus obtained is 0.296% at a pressure of 400 mmH<sub>2</sub>O, 0.586% at 800 mmH<sub>2</sub>O, 0.881% at 1,200 mmH<sub>2</sub>O, 1.178% at 1,600 mmH<sub>2</sub>O, and 1.472% at 2,000 mmH<sub>2</sub>O, which are extremely high.

The resistor elements **R3** and **R4** of the pressure sensor according to Example 11 are considered to be one resistor element. In this case, the sensitivity to a pressure is higher than that of a pressure sensor having only one resistor element.

The change ratios concerning the resistor elements **R1** and **R2**, and **R3** and **R4** have different signs for the following reason. As is shown in Figure 14, an outermost periphery of the metal substrate **1** is completely held by the jig **5**. Accordingly, when a compressive stress is applied to the center **F** of a surface receiving a pressure, a tensile stress is applied to the center **E** of a surface opposite thereto. Then, a compressive stress is applied to an outer peripheral portion **G** of the metal substrate **1** in the vicinity of the jig, and thus a tensile stress is applied to the outer peripheral portion **H** of the metal substrate **1**.

The arrangement of the resistor elements and the electrodes as in Examples 10 and 11 significantly improves the sensitivity to a pressure. A pressure sensor having a still higher sensitivity can be produced by forming the resistor elements on both surface of the metal substrate **1**. The pressure sensor according to Example 10 can measure the sum of the pressures at two points or can detect a difference between the pressures at two points.

#### Example 13

A pressure sensor according to the present invention can be used in a pressure detecting apparatus for detecting a combustion pressure or a manifold air pressure of a vehicle engine.

Figure 15 is a cross sectional view of such a pressure detecting apparatus **10** utilizing a pressure sensor according to Example 5 or 10. The pressure detecting apparatus **10** includes a pressure sensor **7** welded to an outer frame **8**, and a pressure detecting circuit **9** connected to the pressure sensor **7** through a lead wire **6**. The pressure detecting circuit **9** includes a power source, an amplifier, etc. A pressure detected by the pressure detecting circuit **9** is output to an engine controlling computer **13** (Figure 16) through a signal line **26**. As is shown in Figure 16, the pressure detecting apparatus **10** is attached to a side wall of an engine combustion chamber **11** so as to be used as a combustion pressure detecting apparatus **10a** for detecting combustion pressure (absolute pressure). An identical pressure detecting apparatus **10** is attached in a manifold **12**, as is also shown in Figure 16 to be used as an intake pressure detecting apparatus **10b** for detecting the difference between the pressure in the manifold and an atmospheric pressure. For the pressure detecting apparatus **10a**, a pressure sensor according to Example 5 is used, and for the pressure detecting apparatus **10b**, a pressure sensor according to Example 10 is used.

The combustion pressure and the amount of the air inhaled are detected by the pressure detecting apparatuses **10a** and **10b** respectively, and the signals are sent from the engine controlling computer **13** to an electronically controlled EGR valve **14**, thereby precisely controlling the mixing ratio of the air and the fuel. By this system, NO<sub>x</sub> can be reduced by 10% or more compared with the case where neither the combustion pressure detecting apparatus **10a** nor the intake pressure detecting apparatus **10b** is provided.

Conventionally, a semiconductor-type pressure sensor has been used for monitoring pressure in an environment such as the above. Since such a semiconductor-type pressure sensor is inferior in heat resistance, the pressure cannot

be measured with high accuracy in the above environment in which ambient temperature is raised up to 400°C by combustion of the fuel. In contrast, a pressure sensor according to the present invention is excellent in heat resistance as is described in Example 13, and thus can directly detect a combustion pressure. Further, a pressure sensor according to the present invention has a high response speed as is proven by the fact that the pressure can be measured with high accuracy at an engine combustion cycle of several thousand rpm.

#### Example 14

A pressure sensor according to the present invention can also be used in a static pressure detecting apparatus which is provided in a main duct of large- or medium-scale buildings in order to control the amount of air provided by an air conditioning system.

Figure 17 is a cross sectional view of such a static pressure detecting apparatus 18 utilizing a pressure sensor according to Example 5.

The static pressure detecting apparatus 18 includes a pressure sensor 7, O-rings 15, a lead wire 6, a circuit 16 having a power source, an amplifier, etc., and an outer frame 17.

As is shown in Figure 18, the static pressure detecting apparatus 18 is attached on a main duct 21 of an air conditioning system for controlling temperatures of areas A and B by one air conditioner 19. A change in the amount of the air in the main duct 21 is detected by the static pressure detecting apparatus 18. By controlling the rotation speed of a fan 20 and open/close switching of dampers 22 and 23 based on the amount of the air detected by the static pressure detecting apparatus 18, the controlling precision of the temperatures is enhanced, and further electric energy is saved by 12% or more.

#### Example 15

Still another pressure sensor was produced in the same manner as in Example 5 except that electrodes 3 including Au were used. A plate-shaped metal substrate having an outer diameter of 40 mm and a thickness of 60 µm was pre-treated by degreasing, rinsing, acid washing, rinsing, nickel plating, and then rinsing. The resultant metal substrate was immersed in a slurry containing the partially devitrified enamel having the composition of Sample 7 in Table 1, and a DC voltage was applied between a counter electrode and the metal substrate to coat the metal substrate with the partially devitrified enamel. The temperature was raised from room temperature to 880°C in 4 hours, and the resultant metal substrate coated with the glass particles was sintered at this temperature for 10 minutes, thereby forming a glass layer of the partially devitrified enamel. A paste including an organic metal compound containing Au was printed in a pattern shown in Figure 19A on a surface of the glass layer by screen printing, and then sintered at a temperature of 850°C, thereby forming a pair of electrodes 3 each having a thickness of 0.5 µm. A paste mainly including ruthenium oxide and glass frit was printed between the electrodes 3, and then sintered at a temperature of 830°C, thereby forming a resistor element 4 having a size of 1.00 mm x 1.00 mm. In this manner, five pressure sensors having a shape shown in Figure 19A were produced. The resistor element 4 has an average thickness of 10 µm except for a projection 4b at a periphery thereof (Figure 19B and 19C).

#### Example 16

Electrodes 3 each having a thickness of 10 µm were produced in the same manner as in Example 15, namely, by printing a paste including an organic metal compound containing Au on the glass layer by screen printing and then sintering the glass layer with the paste at a temperature of 850°C. A paste mainly including ruthenium oxide and glass frit was printed between the electrodes 3, and then sintered at a temperature of 830°C, thereby forming a resistor element 4 having a size of 1.00 mm x 1.00 mm. In this manner, five pressure sensors having a shape shown in Figure 19A were produced. The resistor element 4 has an average thickness of 10 µm except for a projection at a periphery thereof (Figures 19B and 19C).

#### Comparative Example 6

Electrodes 3 each having a thickness of 10 µm were produced in the same manner as in Example 15 except that a Ag-Pd glass paste was used instead of the paste including an organic metal compound containing Au. A resistor element 4 having a size of 1.00 mm x 1.00 mm was produced in the same manner as in Example 15. In this manner, five pressure sensors having a shape shown in Figure 19A were produced. The resistor element 4 has an average thickness of 10 µm except for a projected portion at a periphery thereof (Figures 19B and 19C).

## Example 17

The pressure sensors according to Examples 15 and 16, and Comparative Example 6 were evaluated for the TCR (temperature dependent change in resistance; the low temperature region: -30 to 25°C; the high temperature region: 25 to 125°C), and the change ratio in the resistance when applied with a pressure of 2,000 mmH<sub>2</sub>O (hereinafter, referred to simply as "resistance"). The sample-to-sample deviation (within lot deviation) in these values was also evaluated. The results are shown in Table 9.

Table 9

	TCR (ppm/°C)		Change ratio in resistance (%) at 2000 mm H <sub>2</sub> O
	Low temp. region	High temp. region	
Example 15-1	11.1	9.8	0.59
15-2	12.0	10.5	0.60
15-3	10.9	9.3	0.59
15-4	11.5	9.9	0.61
15-5	11.7	9.8	0.60
Example 16-1	20.3	13.1	0.60
16-2	23.5	15.6	0.58
16-3	21.9	13.9	0.61
16-4	19.8	13.0	0.59
16-5	22.1	14.7	0.62
Comparative Example 6-1	70.1	35.3	0.63
6-2	85.3	41.2	0.62
6-3	93.3	48.8	0.60
6-4	76.6	36.7	0.58
6-5	81.7	38.9	0.57

As is apparent from Table 9, the pressure sensors according to Examples 15 and 16 having the electrodes 3 containing Au show small values in the change ratio in the resistance, in the TCR, and in the deviation of the TCR. Further, the pressure sensors having the electrodes 3 formed of a paste including an organic metal mainly containing Au has a significantly lower TCR and a significantly smaller deviation thereof than those of the pressure sensors produced according to Comparative Example 6 having the electrodes containing a Ag-Pd glass paste.

The change ratio in the resistance and the TCR of the pressure sensors according to Comparative Example 6 are high for the following reasons.

(1) Since bubbles block the flow of the electric current, the resistance of the resistor element 4 changes in accordance with the number of the bubbles therein. According to Comparative Example 6, a pair of electrodes 3 formed of a Ag-Pd glass paste and each having a thickness of 10 μm are formed and a glass paste including ruthenium oxide and glass frit is printed between the electrodes 3 so as to form a resistor element 4 having a thickness of 10 μm and a shape shown in Figure 19A. In this case, the resistor element 4 has a cross section projected at both ends thereof as is shown in Figure 19B and 19C (meniscus shape). The projection has a thickness which is at least twice as large as the thickness of a flat region of a central portion. The projection includes more bubbles therein than the central portion, and the bubbles block the electric current flow. In the case when a plurality of resistor elements 4 are formed by printing, each resistor element 4 has a different thickness of the projection, and so the plurality of the resistor elements 4 cannot be completely identical with each other. Consequently, each pressure sensor has a different resistance, and has a different TCR.

(2) Glass of the Ag-Pd glass paste for the electrodes 3 and glass of the glass paste mainly including ruthenium oxide and glass frit for the resistor element 4 are mixed with each other during sintering. Accordingly, Ag-Pd in the electrodes 3 and ruthenium oxide in the resistor element 4 each have a different size from the printed size. As a result, the resistance and the TCR are different for each resistor element 4.

(3) In the case when an electrode 3 formed of a Ag-Pd glass paste is used, Ag is reacted with the material of the



resistor element 4 or diffused and mixed therewith, the composition for the electrode 3 is changed in the vicinity of interfaces between the electrodes 3 and the resistor element 4. This also results in the resistance and the TCR which are different for each resistor element 4.

The resistance and the TCR of the pressure sensors according to Examples 15 and 16 are substantially constant for the following reasons.

(1) Since a paste including an organic metal compound containing Au can be formed into a thin film, the electrode 3 can have a thickness of 0.5  $\mu\text{m}$  or less by sintering the paste. Even by use of a usual method for forming a film as thick as 5 to 10  $\mu\text{m}$  (thick film technology), the resultant film has a substantially identical thickness with a film formed by a method for forming a film as thin as 1  $\mu\text{m}$  (thin film technology). Since the film can be formed to be thin, the resultant electrode 3 does not have such a projection as is shown in Figures 19B and 19C. Accordingly, the number of the bubbles inside the electrode 3 is much smaller than the case of Comparative Example 6, resulting in a constant resistance and a constant TCR. In Example 15, the thickness of the electrode 3 is 0.5  $\mu\text{m}$ , and that of the resistor element 4 is 10  $\mu\text{m}$ . The thickness of the electrode 3 is 1/20 of that of the resistor element 4. In the case when the thickness of the electrode 3 is half or less of that of the resistor element 4, the projection of the resistor element 4 is lower than the one shown in Figure 19B. Further, in the case when the thickness of the electrode 3 is 1/3 or less of that of the resistor element 4, the resistor element 4 is not projected.

(2) Since the paste including an organic metal compound containing Au used in Examples 15 and 16 has an extremely low amount of glass than a Ag-Pd glass, the paste for the electrode 3 and the glass in the paste for the resistor element 4 are not mixed with each other. Accordingly, the electrodes 3 and the resistor element 4 are both formed into a size identical with the printed size, resulting in a constant resistance and a constant TCR.

(3) Au is extremely stable, and does not react with other materials as in the case of silver, or is not diffused into the resistor element 4. This also results in a constant resistance and a constant TCR.

The pressure sensors having electrodes 3 including Au according to Examples 15 and 16 each have a smaller TCR (change ratio in the resistance due to the temperature change) than the pressure sensors having electrodes 3 including Ag-Pd according to Comparative Example 6. Therefore, the pressure sensors according to Examples 15 and 16 can be used in a severe environment where the temperature dynamically changes.

#### Example 18

A glass layer was formed on a metal substrate in the same manner as in Example 5. Next, a Ag-Pd glass paste was printed on a surface of the glass layer by screen printing in a shape shown in Figure 20A, and sintered at a temperature of 850°C. In this manner, a pair of electrodes 3 were formed. Each electrode 3 has a width (in the direction of line B-B) of 1.0 mm. A space between the electrodes 3 is 1.0 mm long. A resistor element 4 having a size of 2.0 mm x 2.0 mm was formed as is shown in Figure 20A, and parts of the projection 4b shown in Figure 20B were removed to produced a resistor element 4. In this manner, three pressure sensors were produced. The resistor element 4 has an average thickness of 10  $\mu\text{m}$  except for a projection 4b shown in Figure 20C.

#### Example 19

Three pressure sensors having the shape shown in Figure 20A were produced in the same manner as in Example 18. The resistor element 4 has a size of 1.5 mm x 1.5 mm, and an average thickness of 10  $\mu\text{m}$  except for the projection shown in Figure 20C.

#### Comparative Example 7

Three pressure sensors having the shape shown in Figure 20A were produced in the same manner as in Example 18. The resistor element 4 has a size of 1.3 mm x 1.3 mm, and an average thickness of 10  $\mu\text{m}$  except for the projection shown in Figure 20C.

#### Example 20

Three pressure sensors having the shape shown in Figure 20A were produced in the same manner as in Example 18. The resistor element 4 has a size of 2.0 mm x 2.0 mm, and an average thickness of 5  $\mu\text{m}$  except for the projection

shown in Figure 20C.

#### Example 21

Three pressure sensors having the shape shown in Figure 20A were produced in the same manner as in Example 18 except that electrodes 3 formed of a paste including an organic metal compound containing Au according to Example 15 were used. The resistor element 4 has a size of 2.0 mm x 2.0 mm, and an average thickness of 5  $\mu\text{m}$  except for the projection shown in Figure 20C.

#### Comparative Example 8

Three pressure sensors having the shape shown in Figure 20A were produced in the same manner as in Example 18. The resistor element 4 has a size of 2.0 mm x 2.0 mm, and an average thickness of 15  $\mu\text{m}$  except for the projection shown in Figure 20C.

#### Comparative Example 9

Three pressure sensors having the shape shown in Figure 20A were produced in the same manner as in Example 18. The resistor element 4 has a size of 2.0 mm x 2.0 mm, and an average thickness of 30  $\mu\text{m}$  except for the projection shown in Figure 20C.

#### Example 22

The pressure sensors according to Examples 18 through 21, and Comparative Examples 7 through 9 were evaluated for the TCR (the low temperature region: -30 to 25°C; the high temperature region: 25 to 125°C) and the change ratio in the resistance when applied with a pressure of 2,000 mmH<sub>2</sub>O (hereinafter, referred to simply as "resistance"). The sample-to-sample deviation in these values was also evaluated. The results are shown in Table 10.

Table 10

	Electrode	Size of resistor 4 (mm)	Thickness of resistor 4 ( $\mu\text{m}$ )	TCR (ppm/°C)	
				Low temp. region	High temp. region
Example 18-1	Ag-Pd	2.0 x 2.0	10	20.3	13.3
18-2				18.9	12.9
18-3				17.5	12.1
Example 19-1	Ag-Pd	1.5 x 1.5	10	33.7	19.1
19-2				27.5	17.6
19-3				25.9	15.2
Comparative Example 7-1	Ag-Pd	1.3 x 1.3	10	75.9	33.4
7-2				63.1	30.7
7-3				58.7	29.9
Example 20-1	Ag-Pd	2.0 x 2.0	5	22.1	18.6
20-2				26.3	21.6
20-3				19.4	16.2
Example 21-1	Au	2.0 x 2.0	5	3.2	1.1
21-2				3.3	1.2
21-3				2.9	1.0
Comparative Example 8-1	Ag-Pd	2.0 x 2.0	15	132.6	108.4
8-2				124.9	101.9
8-3				119.6	99.2

Table 10 (continued)

	Electrode	Size of resistor 4 (mm)	Thickness of resistor 4 ( $\mu\text{m}$ )	TCR (ppm/ $^{\circ}\text{C}$ )	
				Low temp. region	High temp. region
Comparative Example 9-1	Ag-Pd	2.0 x 2.0	30	311.6	234.1
9-2				278.6	191.3
9-3				259.9	170.6

As is apparent from the measurement results of the pressure sensors according to Examples 18 and 19, and the Comparative Example 7 shown in Table 10, in the case when the resistor element 4 has a size larger than a portion of 1.0 mm x 1.0 mm sandwiched by a pair of electrodes 3 and parts of the projection 4b are removed, the TCR is small.

This fact is considered to be related to bubbles in the projection 4b as is described below.

In the case of the pressure sensors according to Example 15 shown in Figure 19A, the projection of the resistor element 4 has a length (in a direction of line A-A) of approximately 0.2 mm while a length of the space between the electrodes 3, namely, the intended length of the resistor element 4 is 1.0 mm. Since undesirable bubbles contained in the projection are diffused to the flat central portion, the TCR is not reduced even if the parts of the projection are removed.

In the case of the pressure sensors according to Examples 18 and 19, the resistor element 4 is formed so as to have a length which is 1.4 times or more of the length of the space between the electrodes 3 so that the projection 4b will not be formed on the flat central portion 4a. Accordingly, undesirable bubbles are not contained in the flat central portion 4a, thereby reducing the TCR. In contrast, according to Comparative Example 7, the length of the resistor element 4 is less than 1.4 times of the length of the space between the electrodes 3. Accordingly, undesirable bubbles are contained in the flat central portion 4a, thereby keeping the TCR high.

As is apparent from the measurement results of the pressure sensors according to Examples 18 and 20, and comparative Examples 8 and 9 shown in Table 10, the average thickness of the resistor element 4 except for the projection 4b is preferably 10  $\mu\text{m}$  or less. When the average thickness is more than 10  $\mu\text{m}$ , the TCR increases by the average thickness. The reason for this increase may be attributed to the amount of the bubbles which is increased with the average thickness.

As has been described, a pressure sensor according to the present invention is highly sensitive to pressure, and thus can be used, for example, as a sensor for detecting the vapor pressure of a liquid. As is described in the Examples, a pressure sensor having an extremely high sensitivity is obtained by providing a resistor element having an appropriate shape at an appropriate position.

Since a pressure sensor according to the present invention includes a glass layer formed of a partially devitrified enamel material, the components of the metal substrate and the components of the glass layer are diffused and mixed with each other at an interface therebetween, thereby significantly improving the adhesion of the metal substrate and the glass layer. Further, the glass layer is porous and includes a great number of microscopic foams. The foams act as a buffer against mechanical impact. Accordingly, a pressure sensor according to the present invention can withstand even a strong mechanical impact.

Further, by using an electrode including Au, a pressure sensor is provided that has little deviation in the resistance and the TCR and can thus be used in a severe environment where the temperature dynamically changes is provided. Moreover, by using a resistor element 4 having a thickness of 10  $\mu\text{m}$  or less, a pressure sensor having an extremely small TCR and an extremely small deviation in the TCR is provided.

## Claims

1. A pressure sensor, comprising:

- a plate-shaped metal substrate (1);
- a glass layer (2) which is provided on at least one surface of the metal substrate (1);
- a resistor element (4) which is provided on a surface of the glass layer (2) and has an electric resistance changing in accordance with the degree of strain thereof; and a pair of electrodes (3) connected to the resistor element (4);

characterized in that

the glass layer (2) mainly contains a partially devitrified enamel composition.

2. A pressure sensor according to claim 1, characterized in that the center of a top surface of the resistor element (4) substantially corresponds to the center of the surface of the metal substrate (1); and that the resistor element (4) and the electrode (3) are each symmetrical with respect to the center thereof.
3. A pressure sensor according to claim 1 or 2, characterized in that the resistor element (4) and the electrode (3) each have a shape that provides the resistor element (4) with no directional dependency with respect to pressure or stress.
4. A pressure sensor according to one of the preceding claims, characterized in that the surface of the resistor element (4) and a top surface of the electrode (3) each have a shape selected from the group consisting of a circle, a ring, an arc, and a polygon.
5. A pressure sensor according to one of the preceding claims, characterized in that the surface of the glass layer (2) is provided with a plurality of resistor elements (4) and a plurality of electrodes (3) formed thereon.
6. A pressure sensor according to one of the preceding claims, characterized in that the electrodes (3) each have a thickness of 1/2 or less of the thickness of the resistor element (4).
7. A pressure sensor according to one of the preceding claims, characterized in that the electrodes (3) contain gold.
8. A pressure sensor according to one of the preceding claims, characterized in that the resistor element (4) has a length larger than 1.4 times of a length of a space between the electrodes (3) and is formed by removing a projection at a periphery thereof.
9. A pressure sensor according to one of the preceding claims, characterized in that the resistor element (4) has an average thickness of 10  $\mu\text{m}$  or less except for a projection at a periphery thereof.
10. A pressure sensor according to one of the preceding claims, characterized in that the partially devitrified enamel composition comprises  $\text{SiO}_2$  in the range of 7-33 wt.%,  $\text{B}_2\text{O}_3$  in the range of 5 to 31 wt.%,  $\text{MgO}$  in the range of 20 to 50 wt.%,  $\text{CaO}$  in the range of 0 to 20 wt.%,  $\text{BaO}$  in the range of 0 to 50 wt.%,  $\text{La}_2\text{O}_3$  in the range of 0 to 40 wt.%,  $\text{P}_2\text{O}_5$  in the range of 0 to 5 wt.%, and  $\text{MO}_2$  in the range of 0 to 5 wt.%, where M is one element selected from the group consisting of Zr, Ti and Sn.
11. A pressure detecting apparatus comprising a pressure sensor (7) according to claim 3 which is provided in an engine manifold (12) of a vehicle, wherein an amount of air inhaled into the manifold (12) is controlled by obtaining a difference between a pressure in the manifold (12) and an atmospheric pressure.
12. A pressure detecting apparatus comprising a pressure sensor (7) according to claim 1 which is provided on a wall of a combustion chamber (11) of a vehicle engine, wherein a pressure in the combustion chamber (11) is directly detected.
13. A pressure detecting system for use in a vehicle, which comprises:
  - a pressure detecting apparatus (10, 10b) of claim 11; and
  - a pressure detecting apparatus (10, 10a) of claim 12.
14. A pressure detecting apparatus comprising a pressure sensor (7) of one of claims 1-10 which is provided in a main duct (21) of an air conditioning system, wherein a change in an amount of air in the main duct (21) is detected as a pressure.

#### Patentansprüche

1. Drucksensor mit:
  - einem plattenförmigen Metallsubstrat (1);

einer Glasschicht (2), welche auf zumindest einer Oberfläche des Metallsubstrats (1) vorgesehen ist;  
einem Widerstandselement (4), welches auf einer Oberfläche der Glasschicht (2) vorgesehen ist und einen elektrischen Widerstand aufweist, der sich in Abhängigkeit von ihrem Belastungs- bzw. Verformungsgrad ändert; und  
5 einem Paar von Elektroden (3), die mit dem Widerstandselement (4) verbunden sind;

dadurch gekennzeichnet, daß  
die Glasschicht (2) hauptsächlich eine teilweise entglaste Emailzusammensetzung (partially devitrified enamel composition) enthält.

2. Drucksensor nach Anspruch 1, dadurch gekennzeichnet, daß die Mitte einer oberen Oberfläche des Widerstandselements (4) im wesentlichen mit dem Mittelpunkt der Oberfläche des Metallsubstrats (1) übereinstimmt; und daß das Widerstandselement (4) und die Elektrode (3) jeweils symmetrisch sind im Bezug auf ihren Mittelpunkt.

3. Drucksensor nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß das Widerstandselement (4) und die Elektrode (3) jeweils eine Form haben, die das Widerstandselement (4) mit keiner Richtungsabhängigkeit im Bezug auf Druck oder Belastung bzw. Verformung vorsieht.

4. Drucksensor nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Oberfläche des Widerstandselements (4) und eine obere Oberfläche der Elektrode (3) jeweils eine Form haben, die aus einer Gruppe, bestehend aus einem Kreis, einem Ring, einem Bogen, und einem Polygon, gewählt wurde.

5. Drucksensor nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Oberfläche der Glasschicht (2) mit einer Vielzahl von Widerstandselementen (4) und einer Vielzahl von Elektroden (3), die darauf ausgebildet sind, versehen ist.

6. Drucksensor nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Elektroden (3) jeweils eine Dicke mit der Hälfte oder weniger der Dicke des Widerstandselements (4) haben.

7. Drucksensor nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Elektroden (3) Gold enthalten.

8. Drucksensor nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß das Widerstandselement (4) eine Länge hat, die größer als 1,4 mal die Länge eines Raums zwischen den Elektroden (3) ist, und durch Entfernen eines Vorsprungs an ihrem Umfang.

9. Drucksensor nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß das Widerstandselement (4) eine durchschnittliche Dicke von 10 µm oder weniger hat, außer einem Vorsprung an ihrem Umfang.

10. Drucksensor nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die teilweise entglaste Emailzusammensetzung  $\text{SiO}_2$  im Bereich von 7 bis 33 Gew.-%,  $\text{B}_2\text{O}_3$  in dem Bereich von 5 bis 31 Gew.-%,  $\text{MgO}$  in dem Bereich von 20 bis 50 Gew.-%,  $\text{CaO}$  in dem Bereich von 0 bis 20 Gew.-%,  $\text{BaO}$  in dem Bereich von 0 bis 50 Gew.-%,  $\text{La}_2\text{O}_3$  in dem Bereich von 0 bis 40 Gew.-%,  $\text{P}_2\text{O}_5$  in dem Bereich von 0 bis 5 Gew.-% und  $\text{MO}_2$  in dem Bereich von 0 bis 5 Gew.-% aufweist, wobei M ein Element ist, das aus der Gruppe bestehend aus Zr, Ti und Sn, ausgewählt wird.

11. Druckmeßvorrichtung mit einem Drucksensor (7) nach Anspruch 3, welcher in einem Motorauspuffrohr (12) eines Fahrzeugs vorgesehen ist, wobei die Luftmenge, die in das Auspuffrohr (12) eingesaugt wird, durch das Erreichen einer Differenz zwischen dem Druck in dem Auspuffrohr (12) und dem Luftdruck gesteuert bzw. geregelt wird.

12. Druckmeßvorrichtung mit einem Drucksensor (7) nach Anspruch 1, welcher an einer Wand einer Verbrennungskammer (11) eines Motors eines Fahrzeugs vorgesehen ist, wobei der Druck in der Verbrennungskammer (11) direkt erfaßt wird.

13. Druckmeßsystem zur Verwendung in einem Fahrzeug, welches aufweist:

eine Druckmeßvorrichtung (10, 10b) nach Anspruch 11; und  
eine Druckmeßvorrichtung (10, 10a) nach Anspruch 12.

14. Druckmeßvorrichtung mit einem Drucksensor (7) nach einem der Ansprüche 1 bis 10, welcher in einer Hauptrohrleitung (21) eines Klimaanlage-Systems vorgesehen ist, wobei eine Änderung der Luftmenge in der Hauptrohrleitung (21) als Druck erfaßt wird.

5

## Revendications

1. Capteur de pression, comprenant :

10

un substrat (1) de métal en forme de plaque ;  
une couche de verre (2) qui est incluse sur au moins une surface du substrat (1) de métal ;  
un élément de résistance (4) qui est inclus sur une surface de la couche de verre (2) et a une résistance électrique qui varie en fonction du degré de déformation de celui-ci ; et deux électrodes (3) connectées à l'élément de résistance (4) ;

15

caractérisé en ce que  
la couche de verre (2) contient principalement une composition d'émail partiellement dévitrifié.

20

2. Capteur de pression selon la revendication 1, caractérisé en ce que le centre d'une surface supérieure de l'élément de résistance (4) correspond sensiblement au centre de la surface du substrat (1) de métal ; et en ce que l'élément de résistance (4) et l'électrode (3) sont chacun symétriques par rapport au centre.

25

3. Capteur de pression selon l'une des revendications 1 ou 2, caractérisé en ce que l'élément de résistance (4) et l'électrode (3) ont chacun une forme qui ne confère à l'élément de résistance (4) aucune dépendance directionnelle par rapport à la pression ou à la contrainte.

30

4. Capteur de pression selon l'une quelconque des revendications précédentes, caractérisé en ce que la surface de l'élément de résistance (4) et la surface supérieure de l'électrode (3) ont chacune une forme choisie dans l'ensemble constitué par un cercle, un anneau, un arc et un polygone.

35

5. Capteur de pression selon l'une quelconque des revendications précédentes, caractérisé en ce que la surface de la couche de verre (2) est pourvue d'une pluralité d'éléments de résistance (4) et d'une pluralité d'électrodes (3), réalisés sur celle-ci.

40

6. Capteur de pression selon l'une quelconque des revendications précédentes, caractérisé en ce que les électrodes (3) ont chacune une épaisseur qui est de 1/2 ou moins de l'épaisseur de l'élément de résistance (4).

45

7. Capteur de pression selon l'une quelconque des revendications précédentes, caractérisé en ce que les électrodes (3) contiennent de l'or.

50

8. Capteur de pression selon l'une quelconque des revendications précédentes, caractérisé en ce que l'élément de résistance (4) a une longueur supérieure à 1,4 fois la longueur de l'intervalle entre les électrodes (3), et est réalisé en enlevant une saillie à une périphérie de celui-ci.

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9. Capteur de pression selon l'une quelconque des revendications précédentes, caractérisé en ce que l'élément de résistance (4) a une épaisseur moyenne de 10 µm ou moins, à l'exception d'une saillie au niveau de la périphérie de celui-ci.

10. Capteur de pression selon l'une quelconque des revendications précédentes, caractérisé en ce que la composition d'émail partiellement dévitrifié comprend du SiO<sub>2</sub> selon une teneur comprise entre 7 et 33 % en poids, du B<sub>2</sub>O<sub>3</sub> selon une teneur comprise entre 5 et 31 % en poids, du MgO selon une teneur comprise entre 20 et 50 % en poids, du CaO selon une teneur comprise entre 0 et 20 % en poids, du BaO selon une teneur comprise entre 0 et 50 % en poids, du La<sub>2</sub>O<sub>3</sub> selon une teneur comprise entre 0 et 40 % en poids, du P<sub>2</sub>O<sub>5</sub> selon une teneur comprise entre 0 et 5 % en poids et du MO<sub>2</sub> selon une teneur comprise entre 0 et 5 % en poids, où M est un élément choisi dans l'ensemble constitué par Zr, Ti et Sn.

11. Dispositif de détection de pression comprenant un capteur de pression (7) selon la revendication 3, qui est disposé dans une tubulure (12) d'un véhicule, dans lequel la quantité d'air admise dans la tubulure (12) est contrôlée en

obtenant la différence entre la pression dans la tubulure (12) et la pression atmosphérique.

- 5 12. Dispositif de détection de pression comprenant un capteur de pression (7) selon la revendication 1, qui est disposé sur une paroi d'une chambre (11) de combustion d'un moteur de véhicule, dans lequel la pression dans la chambre (11) de combustion est détectée directement.

13. Système de détection de pression destiné à être utilisé dans un véhicule, qui comprend :

10 un dispositif (10, 10b) de détection de pression selon la revendication 11 ; et  
un dispositif (10, 10a) de détection de pression selon la revendication 12.

14. Dispositif de détection de pression comprenant un capteur de pression (7) selon l'une des revendications 1 à 10, qui est disposé dans un conduit principal (21) d'un système de climatisation, dans lequel une variation de la quantité d'air dans le conduit principal (21) est détectée sous la forme d'une pression.

Fig. 1 A

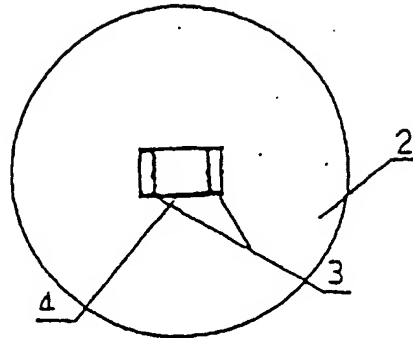


Fig. 1 B

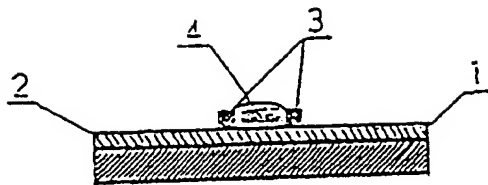


Fig. 3

Fig. 2

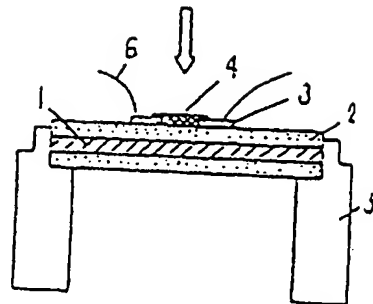
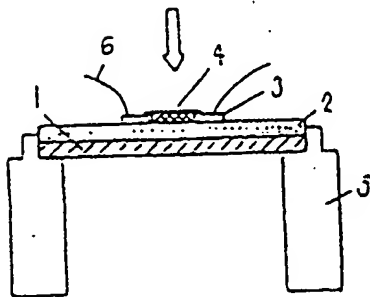




Fig. 4

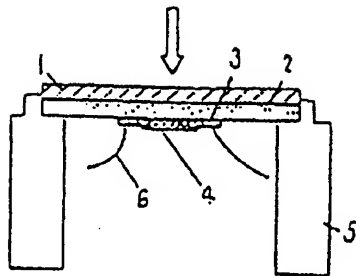


Fig. 5A

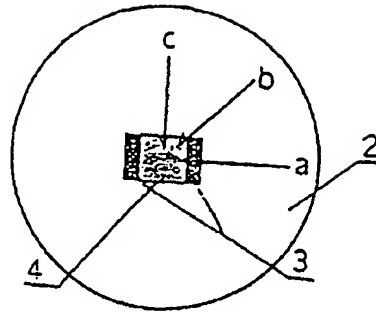


Fig. 5B

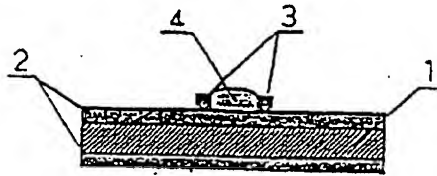


Fig. 6

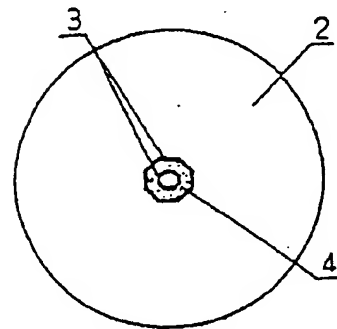


Fig. 7

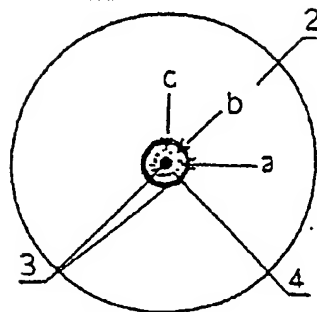


Fig. 8

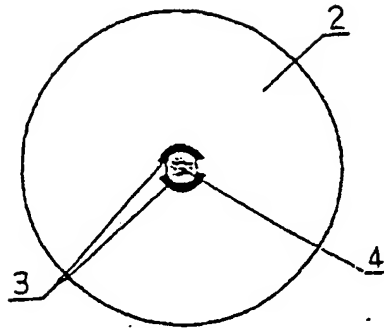


Fig. 9

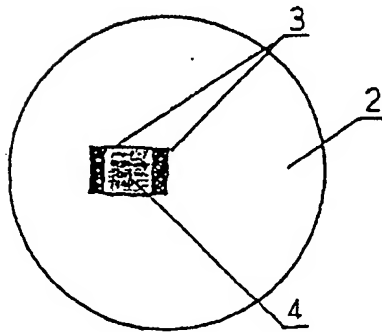


Fig. 10

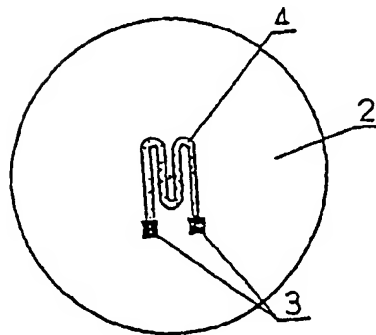


Fig. 11

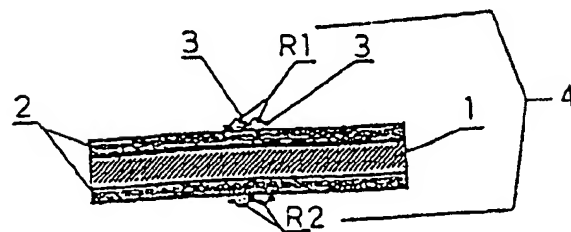


Fig. 12

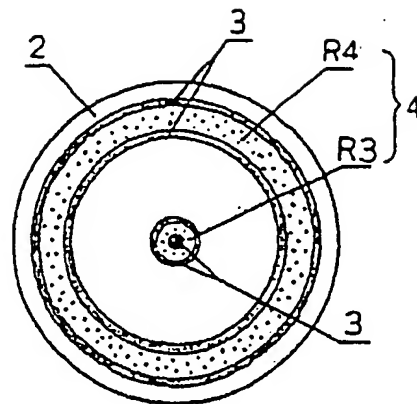


Fig. 13

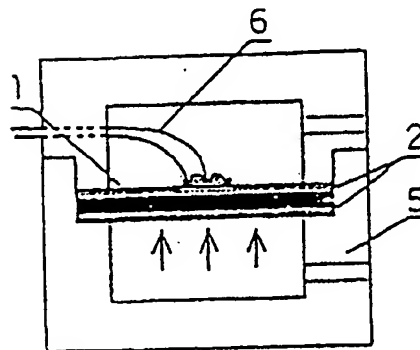


Fig. 14

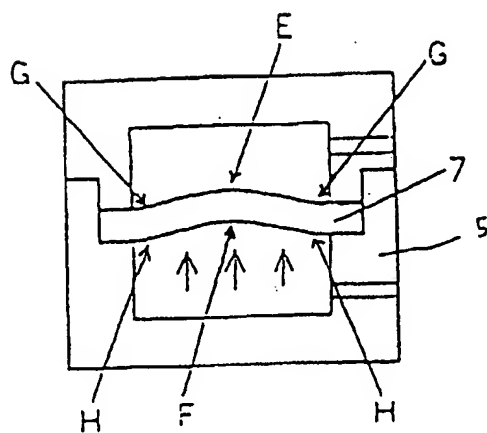


Fig. 15

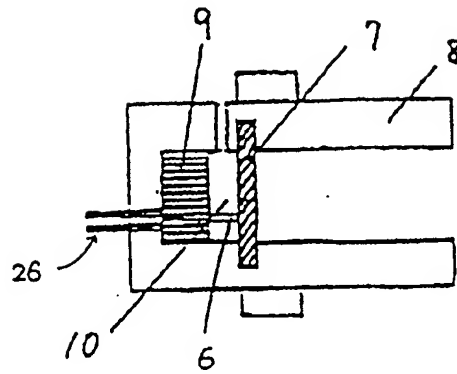


Fig. 16

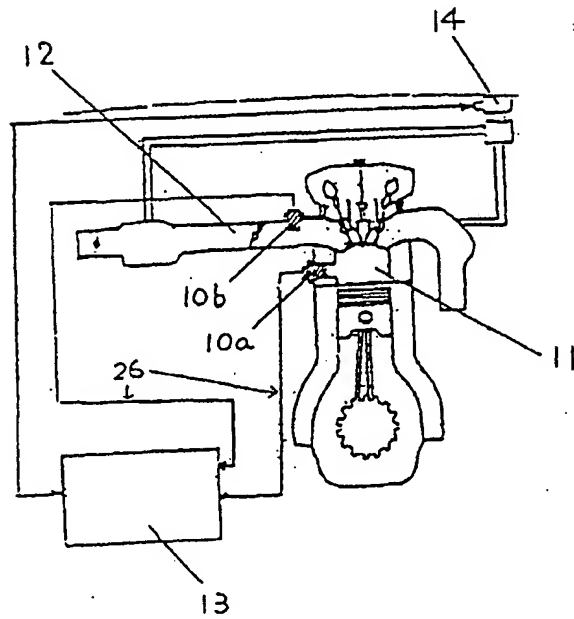


Fig. 17

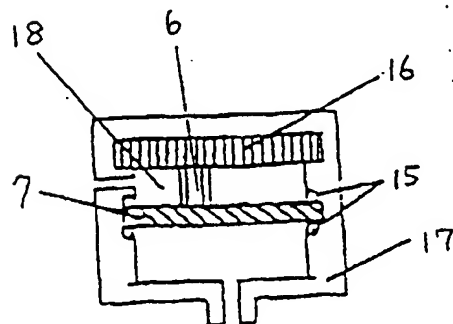


Fig. 18

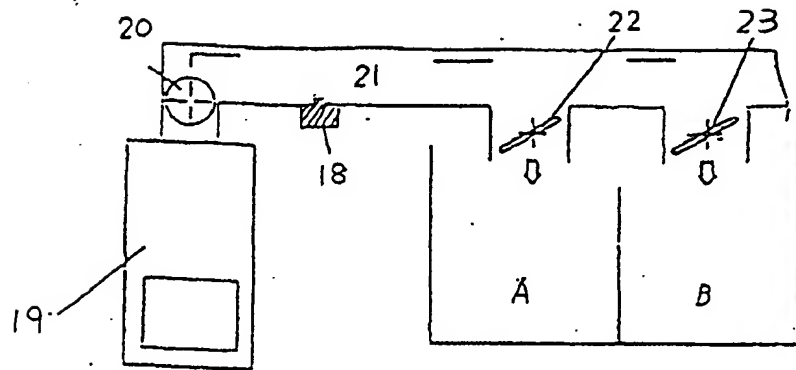


Fig. 19 A

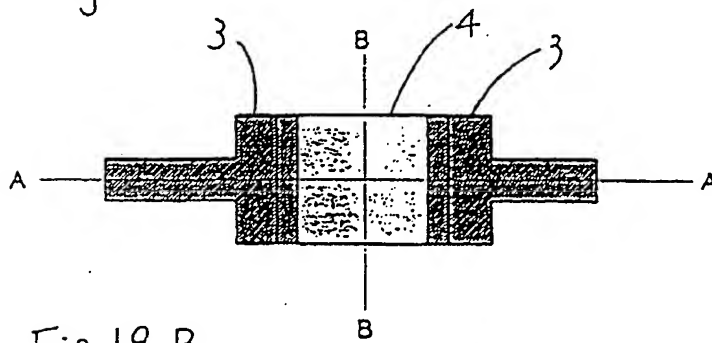


Fig. 19 B

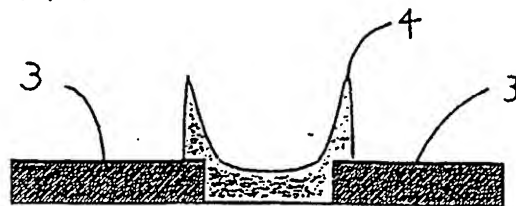


Fig. 19 C



Fig. 20 A

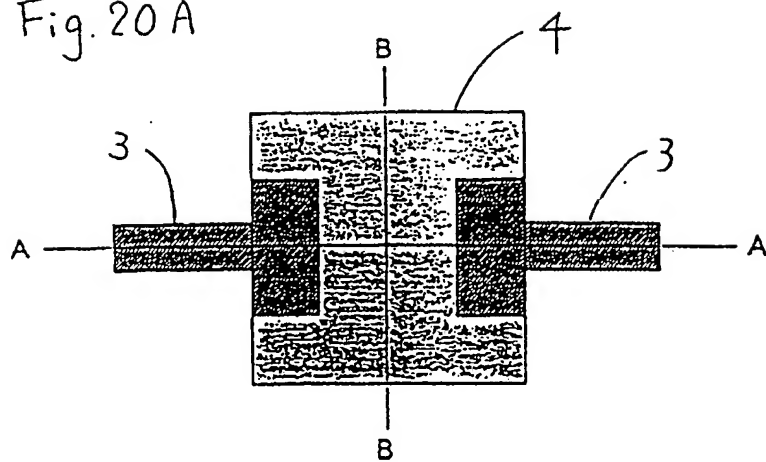


Fig. 20 B

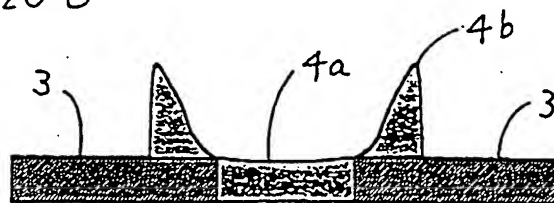


Fig. 20 C

